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Policies and demonstrations of micro-grids in China: A review ☆

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ABSTRACT

Micro-grids are effective concepts and systems to interface renewable and sustainable energy resources into utility, which has been paid significant attention. In this paper, the policies and demonstrations of micro-grids for researches and developments, as well as practical applications in China have been comprehensively reviewed. Many recent policies on renewable energy and micro-grids are summarized, which have been guiding and contributing the development of micro-grids in China. Additionally, the available micro-grids demonstrations in China are also introduced in detail. Finally, the emergency necessaries and trends of micro-grid applications in China have been concluded.

Contents

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1. Introduction

Recently, the traditional transmission and distribution network have met essential challenges on security, reliability, and low emission issues [1–3]. On one hand, the blackout of North American in 2003, due to the unreliable equipment and cascading failure of utility, has turned out that the distributed generation systems are good choices to enhance the security and reliability of utility instead of the centralized one [4,5]. Simultaneously, the extreme climate disasters and geology disasters can also be serious barriers for the security of utility, such as the Ice Disaster in 2007 and Wenchuan Earthquake in 2008 of China [6–8]. As a result, distributed, flexible, and autonomic distribution network are gradually paid much more expectation, which can greatly reduce the power delivery and lower the economic loss because of the disasters. On the other hand, aiming to the global environment pollution and energy crisis, green power and low emission are emergency issues of utility. Taking China for example, the shortage of fossil fuels and greenhouse gas emission-reduction hinder the further economic development; in particular, China has suffered the heavy Haze Weather in 2013. Furthermore, how to interface the randomness, intermittent and uncontrollable renewable energy sources (RESs) into utility is a key problem. Taking such conditions into consideration, distributed generation systems are gotten increasing focuses, which are not only an important supplements of traditional utility, but also can effectively interface the renewable and sustainable resources into utility [9,10].

Micro-grid is a special kind of distributed generation system, which consists of RESs, local loads, energy storage devices, supervisor, protection, and control units [11,12]. It is considered as a better solution of distributed generation system in low-capacity customer-ends. Because of its inverter-oriented configuration, two flexible operation modes (namely islanded mode and grid-tied mode) and its capability to suppress the power fluctuation of RESs due to the embedded energy storage devices can be realized. Additionally, micro-grids are expected to achieve many advanced abilities for utility, such as active/reactive power supporting, customized power quality and reliability, black start, and so on. Therefore, several countries and organizations have carried out many demonstrations to verify the micro-grid concept and its advanced abilities. The micro-grid researches and demonstrations by the Consortium for Electric Reliability Technology Solutions (CERTS) of U.S., the European fifth and sixth research frameworks, and the New Energy and Industrial Technology Development Organization (NEDO) of Japan, are well documented and reviewed in [13–16]. However, the works on micro-grid in China have been hardly introduced as far as now, although the exploitations and applications of RESs and micro-grids have been quickly increased in China recently to deal with the energy crisis, environment pollution, and greenhouse gas emission issues [17].

The main contribution of this paper is to give a comprehensive overview on the policies and demonstrations of micro-grids in China. The rest of the paper is organized as follows. In Section 2, the policies and standards of China on renewable energy applications and micro-grids are summarized. Furthermore, the available micro-grid demonstrations in China are explained and depicted in detail in Section 3. Some emergency necessaries and trends on the micro-grid research and development (R&D) and demonstration in the near future of China are conducted in Section 4. Some conclusions are drawn in Section 5.

2. Policies on renewable energy and micro-grids in China

2.1. Some national laws, regulations, and plans on renewable energy application

China aims to exploit and apply renewable energy due to the numerous coal-fired power plants result in serious pollution, severe emission, and the shortage of fossil fuels. Many policies have been carried out to enhance the development of renewable energy implementations and micro-grid demonstrations in China [18–25]. The status of some policies on renewable energy application is summarized as follows.

- The *Renewable Energy Law* was issued in 2006, in which the renewable energy application is ensured as a national policy. This law gives the basic confirmation for the renewable energy application including wind energy, solar energy, and so on.
- The *On-Grid Price of Renewable Energy Generation and the Cost-Sharing Management Pilot Scheme* was formulated in 2006 by National Development and Reform Commission (NDRC). According to this scheme, on-grid price of wind power should

be guided by the government, and the standard price should be determined by the reference price conducted by the tender form under the guidance of the State Council. Meanwhile, it confirms the on-grid price of renewable energy should be higher than the one of coal-fired plants. The extra cost will be shared by all the Provinces quantized according to the sold electricity of each Province base on the auxiliary price 0.002 Yuan/kWh.

- The *Regulations on Renewable Energy Power Generation* announced by NDRC in 2006 has ensured that the plan and construction of renewable energy systems should be taken into the consideration of each regional grid and province grid. The utility should accept all the electricity generated by RESs. However, the grid-tied renewable energy systems should be guided and managed by the utility.
- The *China National Plan for Coping with Climate Change* published by the State Council in 2007 has presented that the RESs (including large hydro plants) are recommended, in such a way that ratio between the consumed secondary energy and consumed fundamental energy to be increased to 2% by the end of 2010.
- The *Plan for the New Energy Industries* to be promulgated soon by National Energy Board (NEB) may set the cumulative installed capacity of wind turbines and photovoltaic (PV) arrays as 100 GW and 20 GW until 2020.
- To enhance the development of renewable energy exploiting in China, the *Guided Catalog of Renewable Energy Industries* was issued by NDRC in 2005. It is expected to guide the departments of government on policies making, and lead the researchers and investors on demonstrations and technical studies in renewable energy fields. In this guide, the RESs including wind energy, solar energy, biomass energy, geothermal energy, oceanic energy, and hydro energy are paid considerable attention.
- The *Middle- and Long-Term Programs of Renewable Energy Development* was formulated by NDRC in 2007. It looks forward that the renewable energy except hydro energy will cover 1% and 3% of the whole energy forms until 2010 and 2020, respectively. Obviously, it is a conservative prediction, and the installed capacity of renewable energy except hydro energy covers 5.6% of all the installed capacity in China as far as 2012. In 2012, the total installed capacity is 1144.91 GW, while the installed capacities of hydro and thermal power plant are 248.9 GW and 819.17 GW (including coal-fired power 758.11 GW, and gas-fired power 38.27 GW). Besides, the installed capacities of the nuclear power, grid-connected wind power, and grid-connected solar energy are 12.57 GW, 60.83 GW, and 3.28 GW, respectively.
- In 2011, the published *Twelfth Five-Year National Economic Development Plan* and *Plan for Renewable Energy Development* confirm that the installment capacity of wind turbines and PV arrays are 190 TW h and 5–10 GW until the end of 2015.
- In the aspect of micro-grid, the micro-grid considered as an advanced technology of distributed energy supplication was list in the *National Plans for Middle- and Long-term Development of Science and Technology in 2006–2020*, which was announced by the State Council in 2006.
- In 2012, the *Twelfth Five-Year Renewable Energy Development Plan* was promulgated by NEB. In this plan, one hundred of renewable energy demonstration cities and two hundreds of demonstration countries will be established to power the renewable energy future. Particularly, 30 micro-grid demonstrations will be built to explore the new power supply mode until the end of 2015.
- In 2013, the *Twelfth Five-Year Energy Development Plan* was released by the State Council. In this national plan, the target to deeply exploit wind, solar, and biomass energy in centralized and dispersed forms is expected. Until 2015, the installed wind turbines, PV arrays, and biomass generators will reach 100 GW, 21 GW, and 13 GW (including 1 GW municipal solid waste power generators), respectively. The installed capacity of large-scale wind farms in Hebei, West and East of Inner Mongolia, Jilin, Gansu, Xinjiang, Heilongjiang, and offshore wind farms in Shandong, Jiangsu will include 79 GW until the end of 2015. Based on the principles of "on-site generation and consumption" and "orderly development", the centralized PV farms will mainly established in Tibet, Inner Mongolia, Gansu, Ningxia, Qinghai, Xinjiang, and Yunnan. On the other hand, the application of distributed energy resources will be addressed based on the principle "owner-occupied, surplus power to utility and orderly development". Until 2015, the installed capacity of distributed PV arrays will reach 10 GW, and 100 cities for RES demonstration will be carried out. Besides, the renewable energy application in village is also encouraged. Until 2015, 200 counties for RES demonstration and 1000 villages for PV demonstration will be established.
- Simultaneously, the *Management of Distributed Generation* will be published in 2013 by NEB. It is expected that some effective guidelines for the on-grid price of micro-grids will be illustrated. Additionally, the planned installed capacity of PV arrays until 2015 will be increased to 40 GW.
- On the biomass energy, the issued *Notice on the Price Policy on Improving Agricultural and Forestry Biomass Power Generation* and *Notice on the Management of Biomass Power Generation Project Construction* by NDRC in 2010 have carried out a series of measures on the development of biomass energy. As a very important part of the renewable energy exploitation in China, biomass energy is paid more and more attention.
- On the micro-gas turbine, *Guidance on the Development of Distributed Energy of Natural Gas* formulated by NDRC in 2011 has expected that the natural gas to be implemented in the "Combined Cooling, Heating and Power (CCHP)" form by the means of micro-gas turbines. 1000 distributed micro-gas projects and 10 demonstration areas are planned to be built until the end of 2015.
- Some technical regulations to guide the renewable energy interfacing to utility are also carried out, as follows.
  - On wind energy, the *Regulation for the Wind Power Connecting to Utility Power System* is the industrial standard of China. Meanwhile, some other industrial standards are also (or to be) available, like *Management Specification on Wind Power Dispatching Operation* issued in 2010 and *Specification on the Functionalities of Wind power Prediction Software* announced in 2011, and the *Standard on the Test Method for Low Voltage Ride-Through Capability of Wind Turbine* to be published in the near future. Furthermore, the national standard *Technical Rule for Connecting Wind farm to Power System* was released in 2005. And the national standard *Technical Regulation for Design of Large-Scale Grid-Connected Wind Farm* was formulated in 1996 and modified in 2009. Simultaneously, the national standard *Measurement and Assessment of Power Quality Characteristics of Wind Farm* was published in 2006.
  - On solar energy, the *Technical Rule for Grid-Connected Photovoltaic Power Station* was promulgated in 2011 by the State Grid Corporation of China (or State Grid). Besides, the *Technical Rule for Grid-Connected Distributed Resources* was also formulated in 2010 by the State Grid. Additionally, *Technical Regulation for Environmental Impact Assessment of Photovoltaic Power Station* was issued in 2012 by NEB. Furthermore, *Regulation for Design of Photovoltaic Power Station* was formulated as a national standard in 2012.

  - Especially, some regulations are also published to guide the development of distributed energy resources by the State Grid, such as the *Technical Regulation on the Distributed Energy Resources Interfacing to Utility*, the *Specification on the Control and Operation of Distributed Energy Resources Interfacing to Distribution Network* in 2011, and the *Specification on the Functionalities of Supervisor System of Distributed Energy Resources Interfacing to Distribution Network* in 2011.
  - On the energy storage devices interfacing to utility, a set of regulations are released by the State Grid, such as the *Technical Regulation on the Energy Storage System Interfacing to Distribution Network* in 2010, the *Standard on the Test of Energy Storage System Interfacing to Distribution Network* in 2011, the *Specification on the Control and Operation of Energy Storage System Interfacing to the Distribution Network* in 2011, and the *Specification on the Functionalities of Supervisor System of the Energy Storage System Interfacing to Distribution Network* in 2011.
  - On micro-grids, the *Technical Regulations on the Micro-grids interfacing to Distribution Network* was drafted and may be announced in 2013 by the State Grid. Meanwhile, the *Specification on the Test and Acceptance of Micro-grids interfacing* to Distribution Network will be drafted in 2013 by the State Grid.
- On the distributed generation, the *Notice on the Service to Ensure the Distributed Photovoltaic Interfacing to Utility* was released in October, 2012 by the State Grid. As a consequence, the State Grid was open to connect the distributed PV energy to distribution network bellow 10 kV voltage level. The capacity of a PV generation farm under 6 MW can be interfaced to utility by the distribution network under 10 kV voltage rank. To ensure the distributed PV farms can operate stably, *Notice on the Management Measures to Promote of Distributed Photovoltaic Interfacing to Utility* (*Interim*) and *Technical Regulation on the Distributed Photovoltaic Interfacing to Distribution Network* (*Interim*) were also published soon. Furthermore, the enhanced standard *Notice on the Service to Ensure Distributed Energy Resources Interfacing to Utility* was carried out by the State Grid in March, 2013. Thus, the distributed energy resources such as PV arrays, wind turbines, micro-gas turbines, biomass, etc., can be freely connected to utility in the areas maintained by the State Grid.

2.2. Some national platforms for renewable energy

To manage the information for the construction of wind farms in China, the National Wind Power Information Management Center was built in 2009 by the Planning and Design General Institute of Hydropower and Water Resources.

To assist the State Council on the development of renewable energy, China National Renewable Energy Center was established by NDRC.

The National Wind Technology and Testing Research Center, built by the State Grid in 2013, consists of five sub-centers, which locate in North of Hebei, Shandong, Liaoning, Gansu, and Ningxia.

The National Energy Solar Center was built by the State Grid in 2010 and approved by NEB, which aimed to the interface of centralized PV plants, involving plan, key equipment, tests, and researches for PV exploitation.

There were 38 State Energy R&D Centers built by NEB in 2010. In those centers, the Smart Grid R&D Center (Shanghai) in Shanghai Jiao Tong University focuses on the issues on smart grid, including renewable energy, micro-grid, energy storage, vehicle-to-grid and so on. And the Smart Grid R&D Center (experimental) in China Electric Power Research Institute (CEPRI) focuses on smart transmission and distribution network, flexible transmission, micro-grid, customized power, energy storage, smart customer-end, and energy efficiency evaluation.

The Wind and Solar Energy Resources Center, leaded by China Meteorological Administration (CMA), pays an important role in the resource evaluation and power forecast of wind and solar energy.

2.3. National research funds on renewable energy and micro-grids

The national projects and funds on renewable energy and micro-grids R&D are mainly approved by the Ministry of Science & Technology of China and the National Natural Science Foundation of China (NSFC).

From the view of the Ministry of Science & Technology of China, the National Basic Research Program of China ("973 Program") and the National High Technology Research and Development Program of China ("863 Program") are big shares for the renewable and sustainable energy researches. The first project on micro-grid supported by "973 Program", named as "some fundamental researches on the distributed generation system", was carried out in 2009. It aimed to several basic problems on micro-grid applications, which contains eight sub-projects as follows.

  - the mechanism of interaction between micro-grid and utility
  - the mechanism of distributed energy storage to ensure the security and stable operation of utility
  - optimal plan of distribution networks with micro-grids
  - principles and technologies of the protection units of micro-grids and the distribution networks with micro-grids
  - grid-tied control strategies of micro-grids and the coordination control of multiple RESs in a micro-grid
  - power quality analysis and control of the micro-grids and the distribution networks with micro-grids
  - simulation technologies of the micro-grids
  - theories on the optimal operation and approaches on the optimal energy management of micro-grids.

Besides, there were some projects are supported by "863 Program" to validate and demonstrate the micro-grid concept, such as "technologies on the grid-tied, control, and protection of micro-grids", "key technologies of micro-grids involving distributed energy resources", and so on.

From the viewpoint of NSFC, the projects on micro-grid and renewable energy supported by NSFC are summarized in Table 1. It can be found that approximately 15% of total supported projects in electrical engineering field are related to renewable energy, meanwhile there are big parts shared by micro-grid researches.

2.4. The role of the State Grid

The State Grid maintains the main transmission and distribution network of China. As depicted in Fig. 1, seven centralized wind farms (each one contains 10 million kW capacity), numerous centralized solar farms, and many micro-grid demonstrations are connected into the State Grid areas. To guide the manufactures and operations of wind farms, solar farms, and micro-grids, many standards are carried out by the State Grid, and some standards are further published as national standards. Some related standards are indicated in Table 2.

Table 1
Projects supported by NSFC in electrical engineering field in the last few years.

Year	2009	2010	2011	2012
Number of projects on micro-grid/percentage	9/5%	6/2%	13/3%	16/4%
Number of projects on renewable energy/percentage	28/15%	33/12.5%	54/15%	71/17%
Total number of projects	185	264	372	418

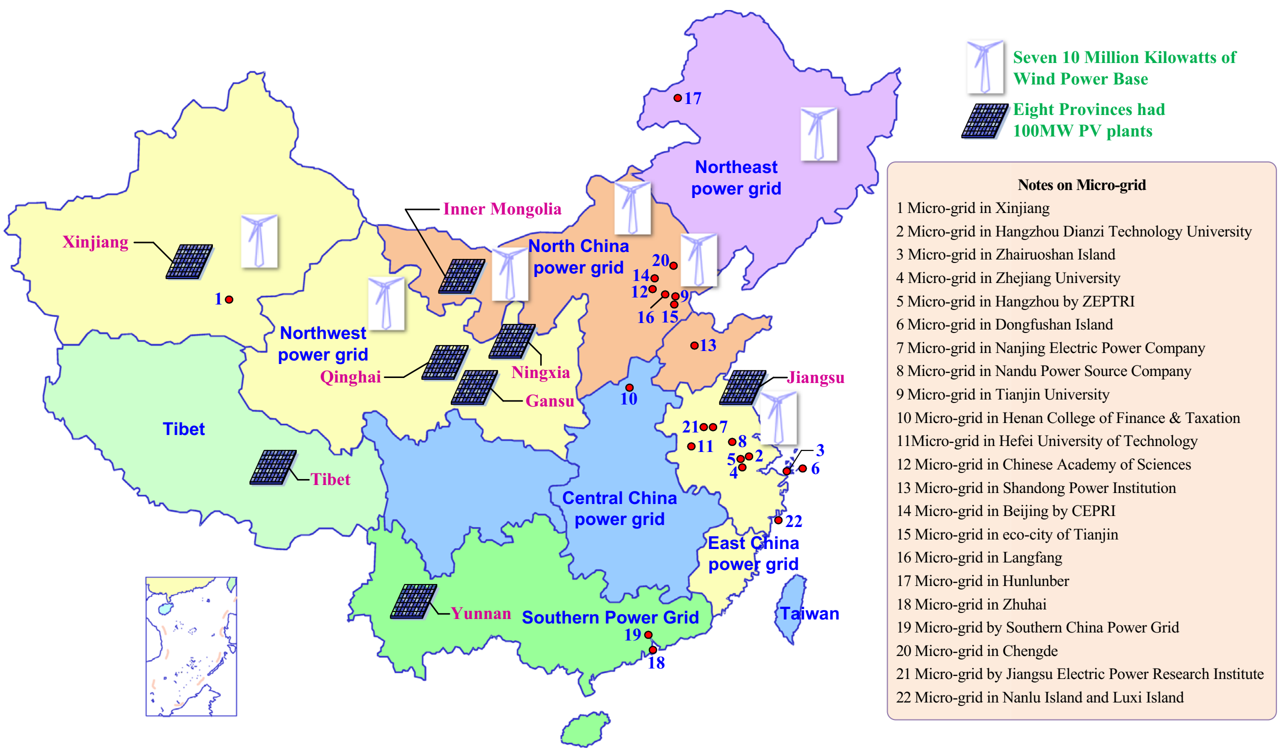

Fig. 1. Some renewable energy farms and micro-grids in China.

2.5. Brief introduce on the renewable exploitation in China

The exploitation of wind energy in China is well documented in [26,27]. It should be noted that seven centralized wind farm are built as shown in Fig. 1. Among them, the Shanghai Donghai Bridge wind farm in Shanghai with 100 MW is the first off-shore wind farm in China. Additionally, another 100 MW off-shore wind farm is planned in Jiangsu. Off-shore wind farm in China is caught more and more focuses, and a series of policies have been published to guide the exploitation of off-shore wind energy in plan, construction, operation, and maintenance aspects [24,25]. To support the development on centralized wind farms, many policies are published as previously mentioned, in such a way that can guide the wind energy producer to reasonably exploit the wind energy.

The status of the exploitation on solar energy in China is introduced in [28–30]. Nowadays, China is the biggest producer of PV arrays all over the world. Nearly 30% of global PV cells are made in China. However, just approximately 2% of these PV cells are installed in China. To increase the installed capacity of PV cells in China, many attempts are carried out as previously mentioned. As a result, there are many centralized PV farms are built as shown in Fig. 1.

On the biomass energy exploitation in China, the status, policies, and barriers on this issue can be found in [31–33]. There are abundant biomass energy, nearly 0.46 billion tons of coal equivalent, can be used each year. However, just 22 million tons of coal equivalent are used as far as now. Thus, there is large space to exploit biomass energy in China. Until the end of 2010, the installed capacity of biomass energy generators is 5.5 GW; where agriculture and forestry biomass generation power is 1.9 GW, waste generation power is 1.7 GW, bagasse generation power is 1.7 GW, and other biomass energy like methane gas is 0.2 GW. By the means of the biomass energy, annual generation power can reach 20 billion kWh, which is equal to 10 million tons of agricultural and forestry residues.

Besides, the statuses of exploitation on other renewable energy resources are also well documented, such as oceanic energy (in particular, tidal energy) in [34–36], geothermal energy in [37], and so on.

2.6. Special focuses

Accompanying with the fast increasing capacity of installed PV arrays and wind turbines in China, many issues should be paid special focuses, such as the lifetime of equipment, handling of waste material used for solar and wind generation, quality management and life cycle assessment of solar and wind power plants, etc.

From the viewpoint of continually increased waste materials of solar and wind generation, the total waste PV arrays of the world will be 24,855 t by the end of 2025. Particularly, this number will reach to 1161,173 t in 2035. There is no doubt that this situation in China is also very severe, and the possible waste materials of PV arrays in China are depicted in Fig. 2, where the lifetime of PV arrays are assumed as 20 years and the mass of the waste PV arrays are considered as 100 t/MW. Similarly, in China, the mass of the waste materials of wind generation is shown in

Table 2
Some standards on renewable energy and micro-grid drawn by the State Grid.

No.	Name	Status	Issued time
1	Technical rules on renewable energy resources interfacing to utility	Ongoing	2014
2	Series standards on the test of the characteristics of renewable energy resources interfacing to utility	Ongoing	2014
3	Series standards on the operation and control of renewable energy resources interfacing to utility	Expected	2014
4	Specification on the functionalities of supervisor system of renewable energy resources interfacing to utility	Expected	2014
5	Series standard on the supervisor devices for renewable energy resources interfacing to utility	Expected	2014
6	Technical regulations on the large-scale energy storage devices interfacing to utility	Expected	2014
7	Series standards on the test of the characteristics of large-scale energy storage devices interfacing to utility	Expected	2014
8	Series standards on the operation and control of large-scale energy storage devices interfacing to utility	Expected	2014
9	Specification on the functionalities of supervisor system of large-scale energy storage devices interfacing to utility	Expected	2014
10	Standard on the operation of grid-tied distributed generation systems (including micro-grid)	Drafted	2011
11	Standard on the communication of grid-tied distributed generation systems	Drafted	2011
12	Guidelines on the devices of distributed generation systems	Drafted	2011
13	Standard on the operation of islanded distributed generation systems (including micro-grid)	Drafted	2012
14	Regulations on the operation and control of distributed energy resources interfacing to distribution network	Expected	Unknown
15	Regulations on the test of distributed energy resources interfacing to distribution network	Expected	Unknown
16	Technical rules on the large-scale application of distributed photovoltaic interfacing to utility	Expected	Unknown
17	Technical rules on the distributed energy resources interfacing to distribution network	Expected	Unknown
18	Technical rules on the energy storage devices interfacing to distribution network	Expected	Unknown
19	Regulations on the operation and control of distributed energy resources interfacing to distribution network	Expected	Unknown
20	Regulations on the test of distributed energy resources interfacing to distribution network	Expected	Unknown
21	Technical regulations on the micro-grid interfacing to utility	Drafted	Unknown

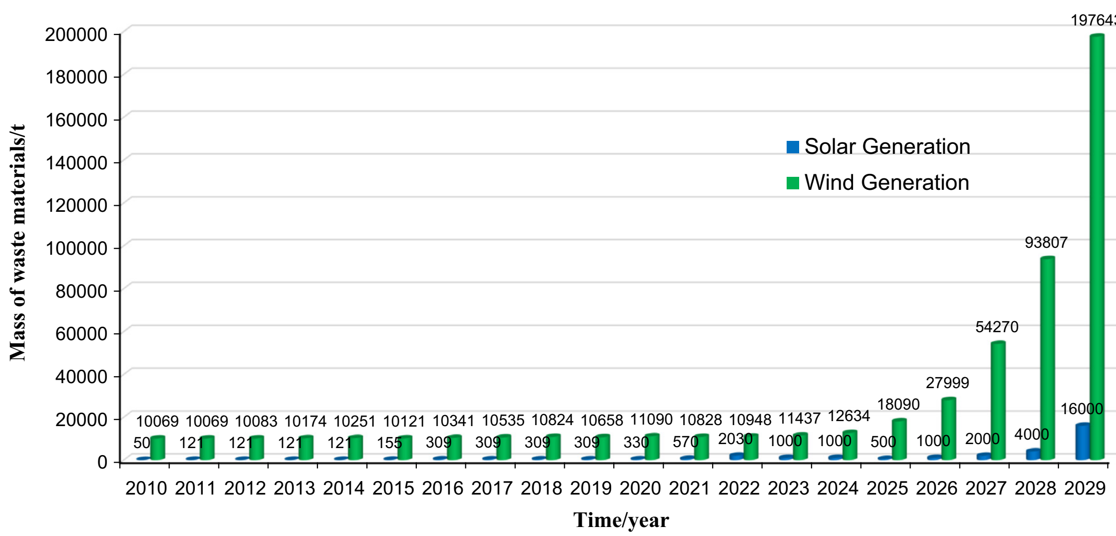

Fig. 2. Mass of the waste materials used for solar and wind generation in China from 2010 to 2029.

Fig. 2, where the lifetime of the wind generation system is assumed as 20 years, too. As can be seen, the generators, blades, and nacelles, etc. will result in a lot of waste materials. Combined with the national plan on wind energy exploitation, the mass of waste materials due to the wind generation is expected to grow to 240 million tons in 2040. Except for the basic materials (PV arrays, wind blades, etc.), some other parts of the solar and wind generation will also result in waste materials and should be caught much attention. These parts are grid-tied inverters, printed circuit boards, batteries for energy storage, etc. In summary, the mass of the waste materials of solar and wind generation matches the fast growth of installment capacity of solar and wind generation in China.

To handle the waste materials, the EU published two commands in 2003, namely the Waste Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC) and the Restriction of Hazardous Substances (RoHS). In particular, the European Parliament has required that the PV arrays should be considered as consumer electronics and be attributed under Appendix IV of the WEEE Directive in 2012. As a result, the waste materials of PV arrays should be well handled and recycled. However, the waste solar and wind generation are paid little attention in China as far as now, and no law is released to deal with the upcoming huge waste materials. However, some laws may be modified and includes some items to handle the waste materials of renewable energy modules.

- The *Regulations on Electronic Information Products Pollution Control* published by the Ministry of Information Industry in 2006 is considered as the RoHS of China.
- Some items on the utilization and disposal of electronic waste materials are also included in the *Solid Law* published by the State Environmental Protection Administration in 2004.
- The *Regulations on the Recycling of Waste Electrical and Electronic Equipment* (draft) released by NDRC in 2004 has made some regulations on the recycling disposal of waste electronic products.
- The *Law to Promote Cleaner Production* and the *Law to Promote Circular Economy* have done some provisions, but their operability is not strong enough.

From the viewpoint of life cycle assessment, some solar, wind, and biomass power plants have done full life cycle assessment (LCA) in China. However, the full LCA of renewable energy projects is not mandatory in China, and there is no law paid attention on this issue. Similarly, there is no law to confirm the system quality management or the lifetime of the equipment, too.

2.7. Analysis and discussion

As mentioned before, China has carried out great efforts and many strategies to handle the global warm and pollution problems. To confirm the renewable energy application, the renewable energy exploitation is ensured as a basic national policy, and some national plans are made to improve the renewable energy industries. Besides, many policies on on-grid price and grid-tied allowance are published by the state and local governments to guide and encourage the renewable energy application. To overcome some common and key technical barriers, many national funds are provided to support the researches on distributed renewable resources and micro-grids in the electrical engineering field. Additionally, the State Grid pays an important role in the renewable energy acceptance and publishes many the regulations and standards.

However, it should be noted that many new challenges of China on renewable energy application are brought out now. Although large-scale centralized wind farms and solar farms are unavoidable due to the inverse distribution of renewable energy resources and power loads in China, the large-scale centralized renewable energy farms are not suitable for high-voltage transmission. Especially, there may not be enough high-voltage transmission lines for the renewable energy. The reported numerous faults of wind farms and solar farms have conducted that the inverter-dominated generation units are fragile and hard to tolerate over-current and bad power quality. In addition, the grid-tied inverters cannot provide significant damping and inertia to the utility like conditional synchronous generators, thus it is hard to maintain and enhance the stability of utility. Therefore, the wind and solar energy are abandoned frequently. Taking wind energy for example, the abandoned wind power is up to 12.3 billion kWh in northwest, north, and northeast China ("three north areas", which lead wind power development in China), which accounts for 16% of the total energy generation ability and 6.6 billion Yuan in 2011. Similarly, the abandoned wind power is nearly accounts for 25% of the total energy generation ability in Gansu and Inner Mongolia in 2011. In 2012, there is more than 100 billion kWh generated by grid-tied wind turbines in China; however, there is approximately 20 billion kWh is abandoned. Wind abandoned is a very critical issue for the large-scale grid-tied wind farms [38].

As far as now, a common acceptance is caught that the micro-grids are good choices for renewable energy applications because the challenges of centralized farms cannot be handled properly at once [39]. Additionally, many benefits and scenarios of utility can be achieved by micro-grids, as follows.

- Friendly and flexible exploitation of renewable energy resources. Compared with centralized farms, inverter-dominated distribution generation (DG) units in small-scale are smaller bulk, lower capital investment, and shorter time for constructing, more flexible and feasible operation. Besides, the DG can reduce the possible bad influence on the environment. Furthermore, the optimal design and construction of DG can avoid some negative problems and reduce the risk.
- Stability and reliability enhancement of utility. The micro-grids are considered as advanced distributed energy sources, and can provide significant support to enhance the stability of utility. In the condition of power oscillation and/or voltage dip at the point of common coupling (PCC), the micro-grid can inject active and/or reactive power into the utility. Additionally, when the utility is fault, the micro-grids can also be split from the utility to ensure the reliable power supply for the local load of the micro-grids. Furthermore, when the disaster occurs, the split micro-grids in islanded operation mode can be employed as key sources to feed the local loads and utility, and enhance black-start ability of the utility.
- Customized power supply. According to the requirement on power quality, the loads in micro-grids can be categorized as key/sensitive loads, controllable/interruptible and adjustable loads. For the key loads, their requirement on power quality is high. They are connected to multiple feeders and can be fed by multiple sources, which can greatly improve the reliability of the power supply for sensitive or key loads. For the controllable loads, they rely on power quality much less. Thus, the controllable loads can be cut off to ensure the power supply of key loads, when the micro-grid is fault.

In summary, compared with centralized wind and solar farms, micro-grids have caught more and more attention recently. As a consequence, many micro-grid demonstrations are carried out to validate and confirm the concept, performance, and functionalities of the micro-grids all over the world. The micro-grids in China are encouraged, and can bring out numerous business and technical opportunities. There are several micro-grid demonstrations are built in China for research and/or power supply for rural areas or islands. To introduce the effect and progresses of China on micro-grids, the available micro-grids are comprehensive reviewed in the following section. Furthermore, the technical demands and trends of micro-grids in China are also summarized in Section 4.

3. Micro-grid demonstrations

The micro-grids have caught common attention recently, many micro-grids R&D and demonstration projects are ongoing all over the world. In China, many universities and institutes have demonstrated some demo micro-grids for research and/or practice. Some available micro-grid demonstrations in China are comprehensively reviewed in the follow sub-sections.

3.1. Micro-grid project in Xinjiang

The first real micro-grid demonstration in China was established in Xinjiang in 2005 by Mitsubishi Electric Co. Ltd., as shown in Fig. 3. The load, whose peak power is 90 kW, can be fed by the distribution network, in coordination with PV arrays, batteries, and the diesel generator in the micro-grid. The total capacity of the micro-grid is 250 kW, which consists of 70 kW PV arrays, a 100 kW diesel generator, and 80 kW batteries.

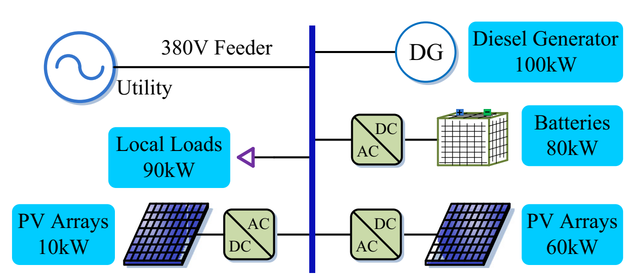

Fig. 3. Configuration of the micro-grid in Xinjiang.

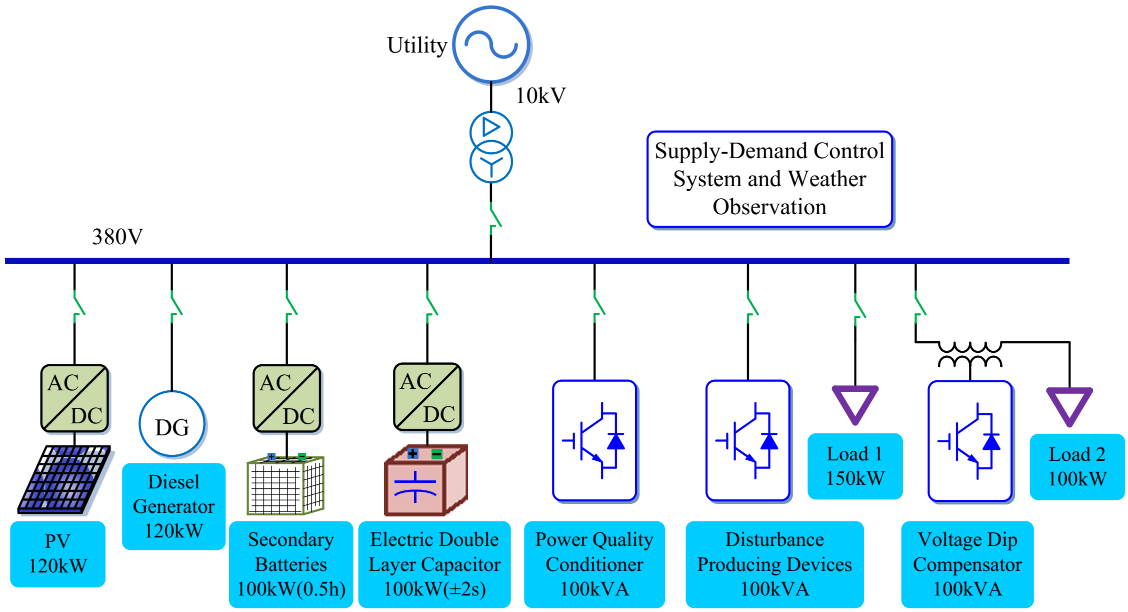

Fig. 4. Micro-grid demonstration in HDTU.

3.2. Micro-grid in Hangzhou Dianzi Technology University

Due to the helpful cooperation of NEDO, Development and Reform Commission of Zhejiang Province, and NDRC, a micro-grid demonstration was built in Hangzhou Dianzi Technology University (HDTU) in 2008, Hangzhou, Zhejiang. This micro-grid was built by HDTU and Shimizu Corporation of Japan, and named as "advanced and stable micro-grid for grid-connected PV". As depicted in Fig. 4, the micro-grid is composed of 120 kW PV arrays, a 120 kW diesel generator, 50 kW lead-acid batteries, 100 kW electric double layer capacitors (EDLCs) (or super capacitors), and a dynamic voltage regulator to enhance power quality. In such a way, two class buildings of HDTU can be fed by the micro-grid. It should be noted that, 50 percentages of the electric power of the micro-grid is generated by the PV arrays. In the daytime, the loads of the buildings can be fully fed by the PV arrays. However, the loads can be fed by the distribution network at night, thanks to the PCC. With the help of the energy storage devices, the power fluctuations of the PCC can be effectively suppressed, which is a very good feature for the utility. The diesel generator is employed to support the voltage and frequency of the micro-grid when the micro-grid is in islanded operation mode.

3.3. Micro-grid demonstrations by Zhejiang University

3.3.1. Micro-grid in Zhairuoshan Island

A micro-grid project for practice is building in Zhairuoshan Island of Zhejiang by Zhejiang University, as demonstrated in Fig. 5. The capacity of this micro-grid is 5 MW, which consists of 300 kW ocean current generators, 3.4 MW wind turbines, 0.5 MW PV arrays, 0.2 MW diesel generators, 0.2 MW EDLCs, and 0.5 MWh Li-Ion batteries (maximum power is 1 MW). A single-bus with multiple segments is employed in the distribution substation to enhance the flexibility and reliability of the micro-grid. From Fig. 5, it can also be found that some centralized capacitors with 50 kvar are installed in bus I and II for reactive power compensation.

The local loads are classed as three categories. The first category is basic loads with 2.3 MW, which are approximately 30 percentages of the total loads. The second one is controllable loads, which are five ice-making devices and can be considered as a 225 kW load in power-valley time. The third one is randomness loads with 65 kW, which are loads of experimental equipment for sea exploiting. It is confirmed that the local loads can be well fed by the power sources of the micro-grid either in grid-tied or islanded operation mode.

The varying-time-constant approach is utilized to properly and optimally coordinate the hybrid energy storage devices, because the response time, power density, and capacity of Li-Ion batteries and ELDCs are hugely different. Besides, a micro-grid-utility controller is also employed to coordinate the frequency control of the micro-grid and the utility. To avoid the blackout of the micro-grid, emergency voltage and frequency controllers of the micro-grid are also properly designed.

3.3.2. Micro-grid in Zhejiang University

To validate the micro-grid in Zhairuoshan Island previously mentioned, a mini micro-grid is built to emulate the micro-grid for experimental validation. The micro-grid is located at Yuquan Campus of Zhejiang University, Hangzhou, Zhejiang. Beside to support the establishing of the micro-grid in Zhainuoshan Island, the micro-grid in Yuquan Campus can also be used for some other micro-grid R&D projects, in which a 5 kW wind turbine, 10 kW PV arrays, 20 kW Li-Ion batteries, 4 kW ELDCs, a 5 kW diesel generator, and some other local controllable or uncontrollable loads are integrated, as shown in Fig. 6. In such micro-grid, a 30 kW fuel cells and 20 kW multi-functional grid-tied inverters (MFGTIs) are also embodied. It should be noted that the MFGTIs have validated that, the grid-tied inverter cannot only interface renewable energy into utility, but also can enhance the power quality of the micro-grid.

3.4. Micro-grid by Zhejiang Electric Power Test & Research Institute

3.4.1. Micro-grid in Hangzhou

In Hangzhou, Zhejiang Electric Power Test & Research Institute (ZEPTRI) built a micro-grid demonstration in 2010, whose configuration is described as shown in Fig. 7 [40]. It can be seen that the micro-grid consists of 60 kW PV arrays, a 30 kW Doubly-Fed Induction Generator (DFIG) emulator, two 5 kW direct-driven wind turbines, a 250 kW diesel generator, a 250 kW flywheel energy storage device, 168 kW h (100 kW) lead-acid batteries, and

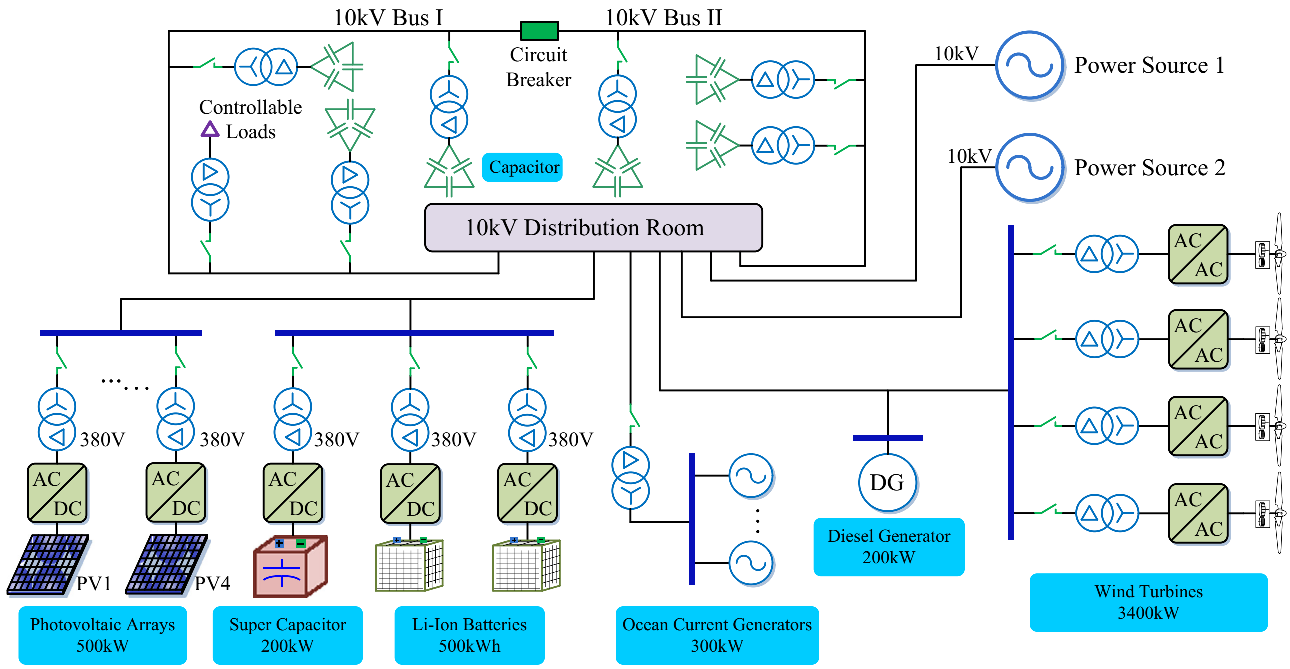

Fig. 5. Configuration of the micro-grid in Zhainuoshan Island.

four load emulators. It should be noted that the micro-grid includes two sub-micro-grids, namely micro-grid A and B, and each one cannot only independently operate, but also can be integrated as a big micro-grid. Besides, there are some line-emulators in the micro-grid, based on which some different kinds of faults can be achieved.

The micro-grid utilizes hierarchical control strategy, in which four parts are integrated. The first part is operation mode controller, which control the batteries to work in grid-tied, islanded, and standby modes. The second part is a supervisor to receive the information of Feeder Terminal Units (FTUs) and sent to center substation. The third part is the micro-grid central controller to manage the micro-sources in the micro-grid. The last one is the optimal controller, which is able to coordinate the utility and the micro-grid, balance the state of charge (SOC) of batteries, dispatch active/reactive generation of the micro-sources, and cut off loads.

3.4.2. Micro-grid in Dongfushan Island

In Dongfushan Island, Zhejiang Province, the ZEPTRI built a micro-grid to provide the electricity to the island loads in 2011. The configuration of the micro-grid is depicted as shown in Fig. 8. It can be found that the micro-grid consists of 100 kW PV arrays, seven 30 kW wind turbines, a 200 kW diesel generator, and two 1000 A h batteries. The local loads contain some controllable loads to desalinate seawater with 50 t/day or 24 kW.

To enhance the stability and reliability of the micro-grid and maximally harvest renewable energy, the batteries and the diesel generator in the micro-grid all can work as the main power for the voltage and frequency supporting. On one hand, when the SOC of the batteries is high, it can act as main source, so the batteries supports the voltage of the micro-grid and balance the demanded and generated power flow. On the other hand, when the SOC of the batteries is low, the diesel generator is chosen as the main source of the micro-grid and charges the batteries. According to the generation of wind turbines and PV arrays, the main source should be optimally chosen, and the micro-grid should be transferred seamlessly from different main source (batteries to diesel generator, or diesel generator to batteries) operation modes.

3.4.3. Micro-grid in Nanjing Electric Power Company

In the Complex Technology Building of Nanjing Electric Power Company (NEPC), a micro-grid associated with a 15 kW wind turbine, 30 kW PV arrays, and 200 Ah batteries was established by ZEPTRI in 2011, as depicted in Fig. 9. In islanded operation mode, the batteries acted as energy storage device are utilized to balance the power flow of the micro-grid. Besides, the batteries are also employed to suppress the power fluctuations due to the randomness of wind energy in grid-tied operation mode. It is worth nothing to note that the micro-grid can be seamlessly transformed between the grid-tied mode and islanded mode.

3.4.4. Micro-grid in Nandu Power Source Company

The framework of the micro-grid in Nandu Power Source Company is illustrated in Fig. 10. This company produces energy storage devices, and its peak-valley power of loads is similar with the one of the utility loads. Therefore, the fees for power supply from the utility will be greatly increased due to the peak-valley electricity price. So the company was motivated to build a micro-grid associated with different kinds of energy storage devices for experimental test in 2010. The micro-grid consists of 55 kW PV arrays, 250 kW (480 V/1 kAh) lead-acid batteries, 100 kW (500 V/1 kAh) Li-ion batteries, and 100 kW EDLCs.

3.5. Micro-grid in Tianjin University

There is a micro-grid demonstration in Tianjin University, as shown in Fig. 11. In this micro-grid, 10 kW PV arrays, 30 kW Li-ion batteries, a 30 kW wind power simulator, a 40 kW load simulator, and EDLCs are integrated.

3.6. Micro-grid in Henan College of Finance & Taxation

As shown in Fig. 12, a micro-grid with 380 kW PV arrays, two 100 kVA/100 kWh batteries, and a micro-grid controller was established in Henan College of Finance & Taxation (HCFT) in 2010. The PV arrays are installed on the roof of seven dormitories to supply the power loads of dormitories and the dining hall.

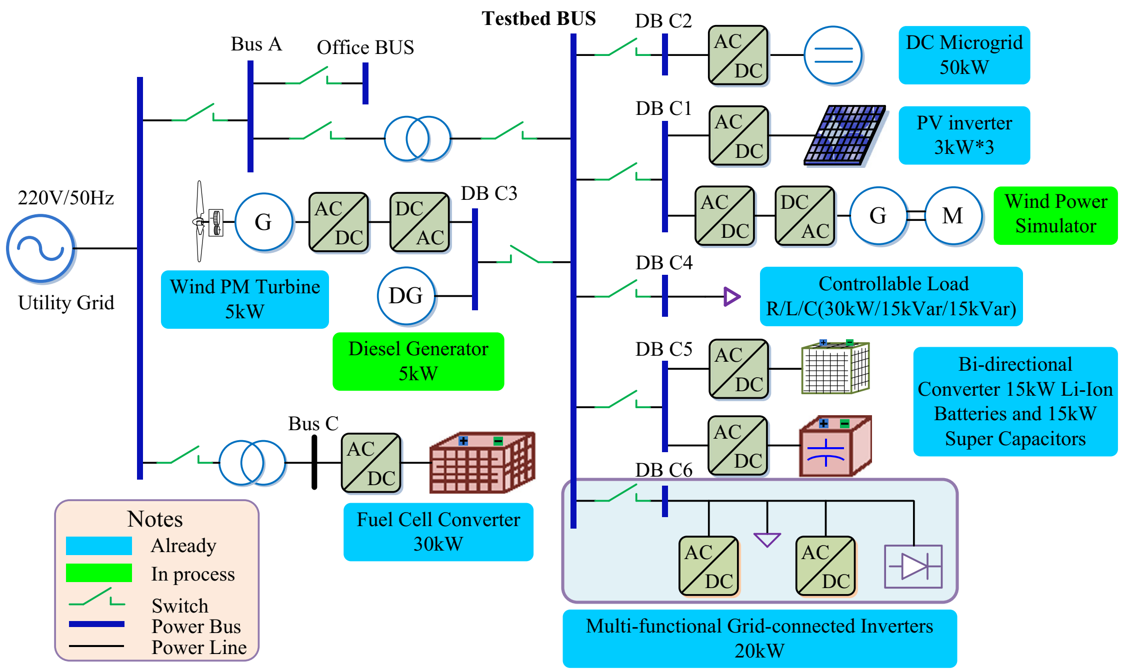

Fig. 6. Schematic diagram of the micro-grid in Yuquan Campus of Zhejiang University.

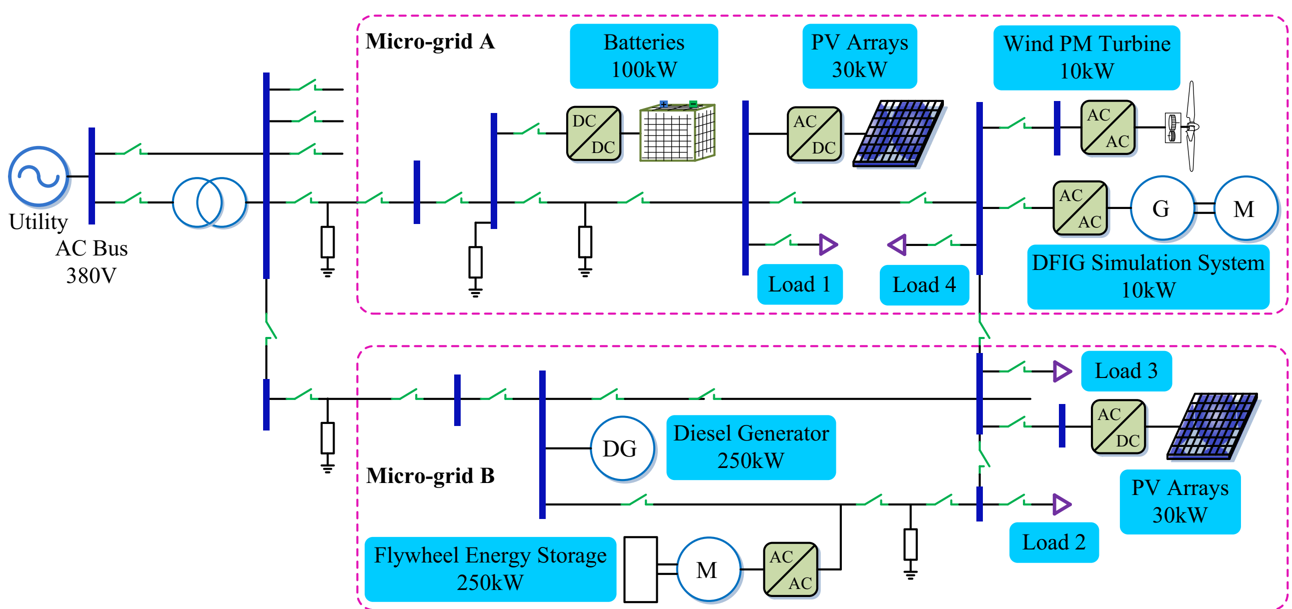

Fig. 7. Schematic of the micro-grid in Hangzhou by ZEPTRI.

3.7. Micro-grid in Hefei University of Technology

In Hefei University of Technology (HFUT), a micro-grid demonstration is built based on its available dynamic emulator laboratory. In such micro-grid, 20 kW PV arrays, two 30 kW wind turbine emulators, 5 kW fuel cells, 300 Ah batteries, and two 15 kW utility emulators are integrated, as shown in Fig. 13. Additionally, a hierarchical controller is carried out to coordinate the micro-sources in the micro-grid.

3.8. Micro-grid in Chinese Academy of Sciences

In Beijing, a micro-grid demonstration has built by Institute of Electrical Engineering, Chinese Academy of Sciences (CAS), as depicted in Fig. 14. In this micro-grid, 30 kVA lead-acid batteries, 15 kW PV arrays, 16 kW Asynchronous Wind Turbine (AWT), and some local loads are integrated.

3.9. Micro-grid in Shandong Power Institution

In Shandong Province, a micro-grid is built by Shandong Power Institution. As introduced in Fig. 15, the micro-grid consists of 15 kW PV arrays, a 15 kW wind generator, a 30 kW DFIG emulator, and a 43 kW smart load system. The micro-grid is utilized to research the dynamic and steady characteristics of solar and wind energy systems, and the energy management of the micro-grid.

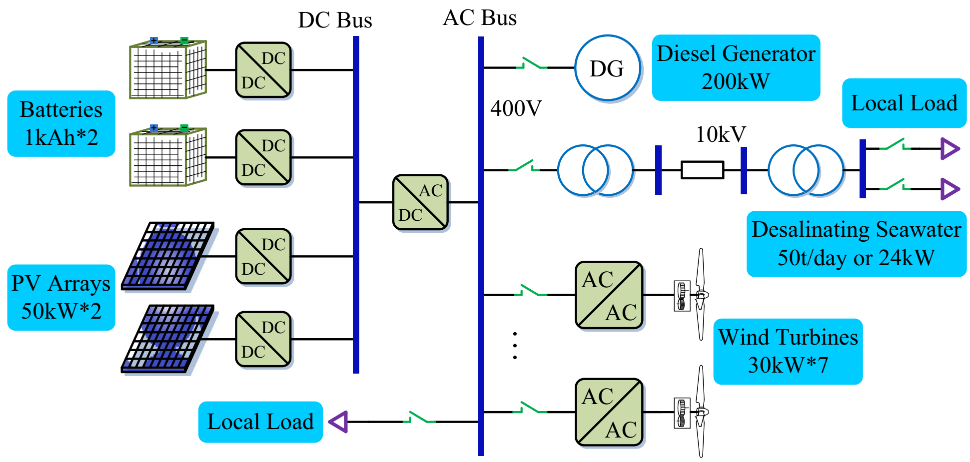

Fig. 8. Configuration of the micro-grid in Dongfushan Island.

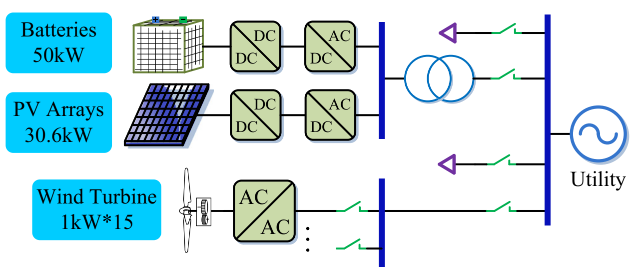

Fig. 9. Framework of the micro-grid in NEPC.

3.10. Micro-grids by China Electric Power Research Institution

3.10.1. Micro-grid in Beijing

In Beijing, a micro-grid is building by CEPRI, which contains 40 kW PV arrays, a 30 kW DFIG simulator, a 30 kW diesel generator, a 100 kW utility simulator, 42 kW Li-ion batteries, and 20 kW lead-acid batteries, as displayed in Fig. 16.

3.10.2. Micro-grid in eco-city of Tianjin

A micro-grid designed by CEPRI was realized in 2011 and located at the eco-city in Tianjin supported by the cooperation of China and Singapore. Its configuration is demonstrated in Fig. 17. In such micro-grid, 30 kW PV arrays, a 6 kW wind turbine, loads of business hall for lighting (10 kW) and power charging (5 kW), 25 kW $\times$ 2 h Li-ion batteries, as well as some supervisors, protections, and controllers are integrated.

3.10.3. Micro-grid in Langfang

Another micro-grid demonstration designed by CEPRI and built by Xinao Energy Company is the micro-grid in Langfang, Hebei, which is an important part of the eco-city of Xinao in Langfang. It was established in 2011 to exhibit the products of the company on biomass energy, wind/solar hybrid power generation, and micro-grid. The micro-grid is integrated in the smart building of the eco-city, which consists of 100 kW PV arrays on the roof, a 150 kW micro-gas turbine worked in CCHP mode, a 2 kW wind turbine, and 100 kW $\times$ 4 h batteries, as indicated in Fig. 18. It can satisfy the power demand of the building and some other industry loads of the eco-city.

3.10.4. Micro-grid in Hunlunber

To power the urban rural agricultural and pastoral areas of east part of Inner Mongolia, a micro-grid was built by CEPRI in Chenbarhu, Hulunber in 2012. As shown in Fig. 19, the micro-grid contains 110 kW PV arrays, 50 kW wind turbines, and 42 kW batteries. The micro-grid is connected to 35 kV distribution network, and meets the power demand of herdsmen's houses and dairy farms.

3.11. Micro-grid in Zhuhai

In 2012, a micro-grid demonstration was built by Singyes Solar Company in Dongao Island, Zhuhai, Guangdong. As indicated in Fig. 20, the micro-grid involves 300 kW diesel generators, 1 MW PV arrays, 50 kW wind turbines, diesel generators, and 2 MV A h batteries. As a result, at least 70 percentages of the load demand can be fed by the renewable energy resources.

3.12. Micro-grid by Southern China Power Grid

With the financial support from “863 Program”, a micro-grid was built in Foshan Power Electric Company by Southern China Power Grid in 2010, as indicated in Fig. 21. This micro-grid consists of three 200 kW CHHP generators and a LiBr absorption chiller to supply the cool air to the building. The micro-grid aims to reach the energy efficiency of 75 percentages. In the grid-tied operation mode, the CHHP generators satisfy the power demand of the building, and the shortage power is provided by the utility. The emission of micro-gas turbines is absorbed by the chiller and changed into cool air to meet the cool demand of the building. And the shortage cool can be supplied by the central air conditioner.

3.13. Micro-grid in Chengde

In 2012, a micro-grid was established in an eco-country of Chengde, Hebei. It can confirm the power demand of local residents and sell the surplus electricity to the utility. In such a way, some other rural areas can be powered by micro-grids. As indicated in the overview of the micro-grid, 80 kW/128 kWh batteries, 50 kW PV arrays, and 60 kW wind turbines are embedded in, as depicted in Fig. 22. Notation that an active power filter (APF) is installed to enhance the power quality of the micro-grid. Besides, some measurement meters, power quality supervisor, and energy management system (EMS) are utilized.

3.14. Micro-grid by Jiangsu Electric Power Research Institute

In 2013, a micro-grid was built by Jiangsu Electric Power Research Institute (JEPRI) with the aid of CEPRI. As demonstrated in Fig. 23, in the micro-grid, 30 kW PV arrays, 100 kW Li-ion batteries, a 120 kW

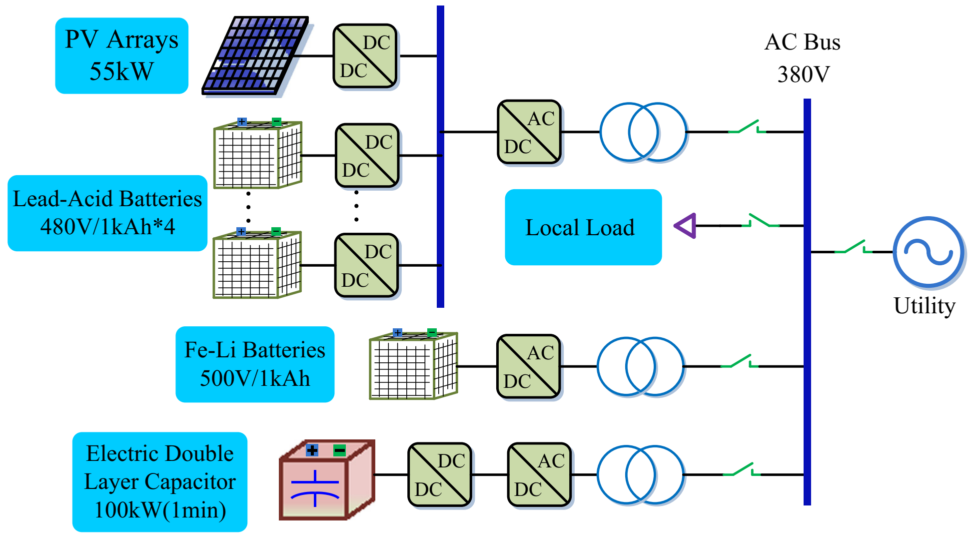

Fig. 10. Micro-grid in Nandu Power Source Company.

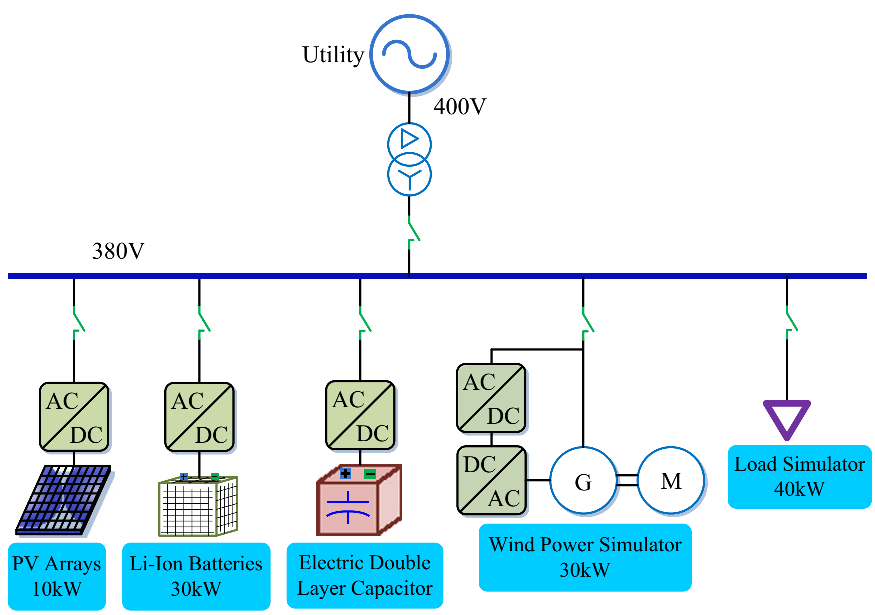

Fig. 11. Configuration of the micro-grid in Tianjin University.

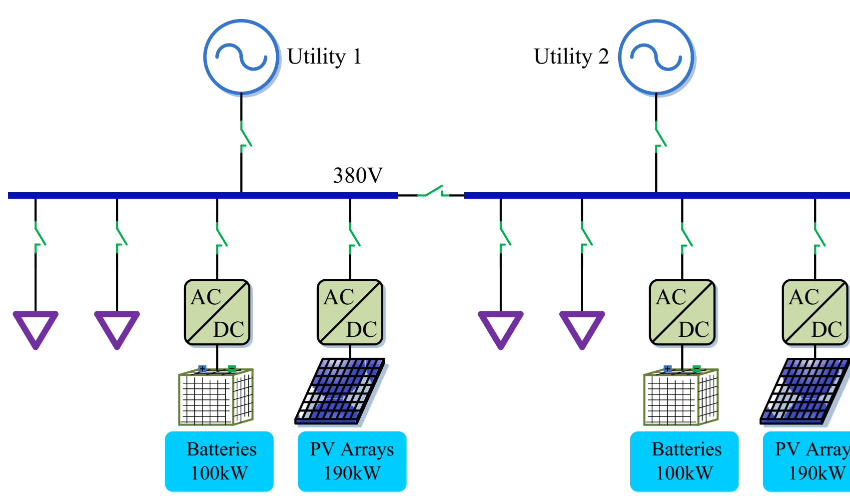

Fig. 12. Framework of the micro-grid in HCFT.

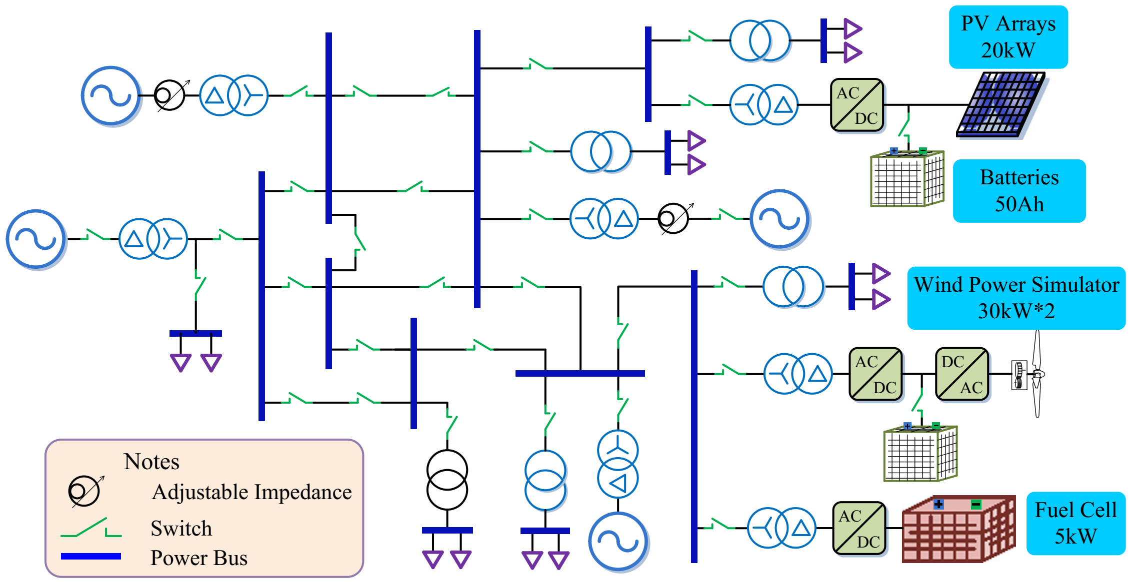

Fig. 13. Configuration of the micro-grid in HFUT.

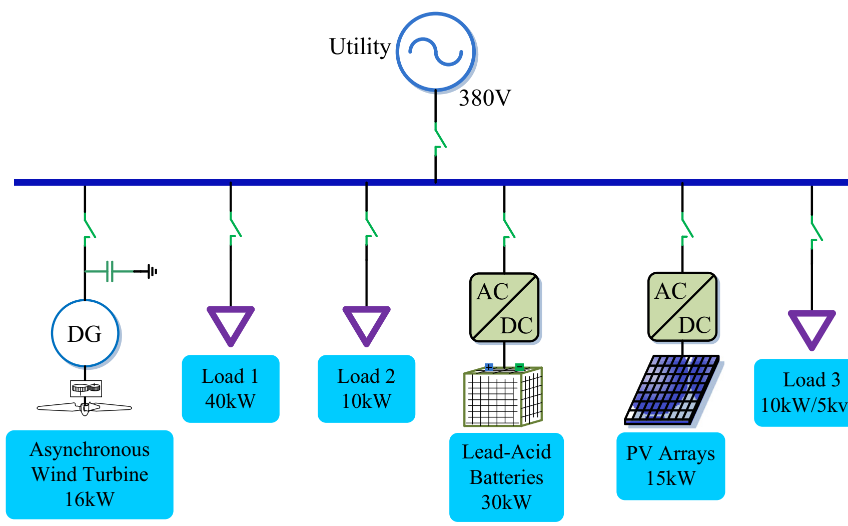

Fig. 14. Framework of the micro-grid in Beijing by CAS.

diesel generator, a 10 kW wind turbine simulator, and some local loads are integrated. Meanwhile, an EMS, protection units, and a coordination controller are included. Additionally, the strategies on operation control and experimental test are carefully designed.

3.15. Other demonstrations

Excluding the micro-grid demonstrations mentioned above, some other micro-grids are also ongoing. For example, the micro-grid in Nanlu Island and Luxi Island in Zhejiang are supported by "863 Program" (named as "key technologies of micro-grids involving distributed energy resources"). In the micro-grid of Nanlu Island, ten 100 kW wind turbines, 545 kW PV arrays, 30 kW ocean current generators, 1.6 MW diesel generators, and batteries of electrical vehicles for energy storage. In the micro-grid of Luxi Island, 1.56 MW wind turbines, 0.3 MW PV arrays, 1 MW × 2 h lead-acid batteries, and 0.5 MW × 30 s EDLCs are planned.

Besides, some micro-grids based on CHHP generators are (or will be) built in Beijing, Inner Mongolia, Shenzhen, and Xiamen.

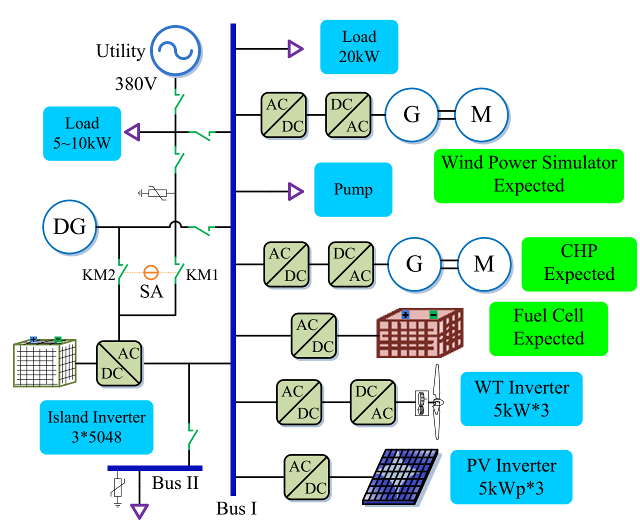

Fig. 15. Schematic of the micro-grid by Shandong Power Insitution.

4. Features, necessaries, and trends of micro-grids in China

4.1. Features of the micro-grid demonstrations in China

The distribution of the available micro-grid demonstrations are indicated in Fig. 1. It can be seen that the micro-grids are mainly distributed in the eastern and coastal parts of China. The typical features of the micro-grid demonstrations in China can be conducted as follows.

- High effective and flexible interfacing of renewable energy resources to meet the green and low emission objectives.
- The capability of power supply for urban areas to satisfy the electric requirements of urban countries. Note that rural electrification is important part of the *Twelfth Five-Year National Economic Development Plan* of China.
- Exploiting the sea resources and giving a novel solution for power supply of islands.
- Adapting power quality enhancement and customized power quality demands of different kinds of loads.
- Improving the reliability and security of the traditional utility, and enhancing the capability of utility to cope with disasters. In such conditions, the micro-grids can be utilized as backup sources for the black-start of the utility.
- The micro-grid is also viewed as a very important part of active distribution network and smart grid to fulfill the traditional utility.

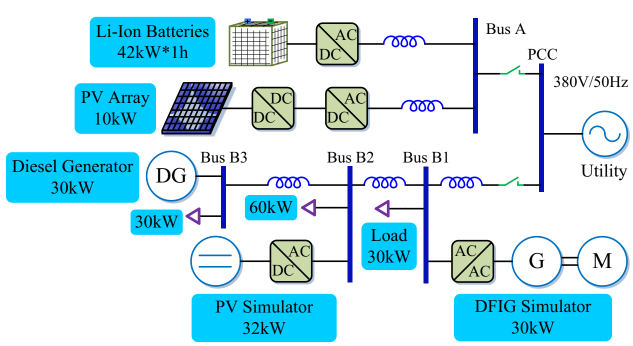

Fig. 16. Configuration of the micro-grid in CEPRI.

4.2. Technical necessaries and trends of micro-grids in China

Although there are so many micro-grid demonstrations are built in China in the last few years, some key technologies are still emergently necessary to make the micro-grid perfectly coordinate with distribution network and some other micro-grids. Some important technical necessaries or trends of the micro-grids in China, even maybe the world, can be summarized as follows.

- Optimal selection of location, as well as the capacities of different kinds of renewable energy resources and energy storage devices. Some documents have investigated the optimal micro-grid location in distribution network, taking into cost, power quality, and reliability of the utility [41]. Besides, some software, such as the Homer developed by the National Renewable Energy Laboratory (NREL) of U.S. [42], can be utilized to optimally obtain the installment capacities of RESs. However, much more attention should be paid to multi-objective optimization models for this issue and their embedded into some advanced software. It should be noted that the cost and performances of different energy storage devices, i.e. Li-ion batteries, lead-acid batteries, flywheel, and

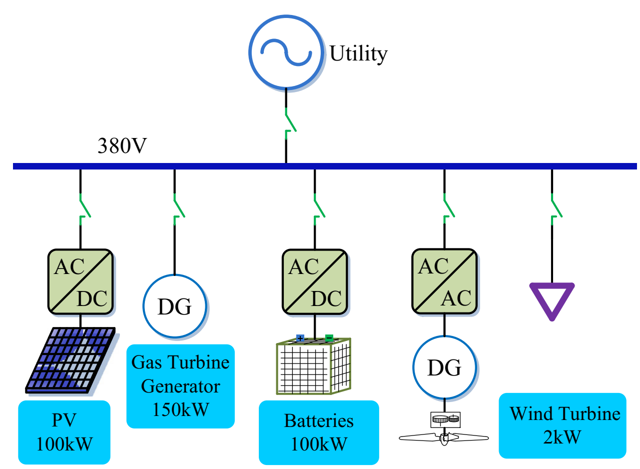

Fig. 18. Schematic of the micro-grid in the eco-city of Langfang.

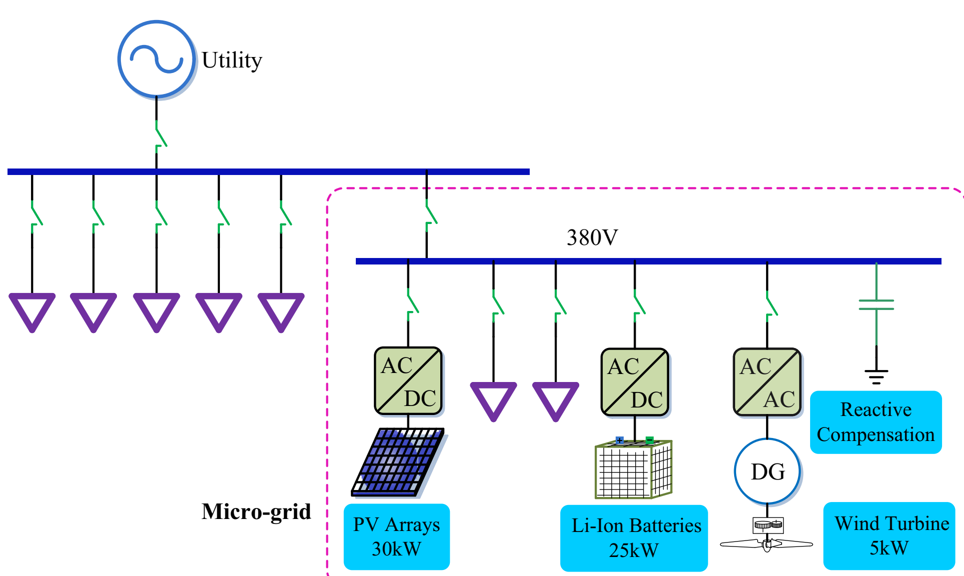

Fig. 17. Configuration of the micro-grid in the eco-city of Tianjin.

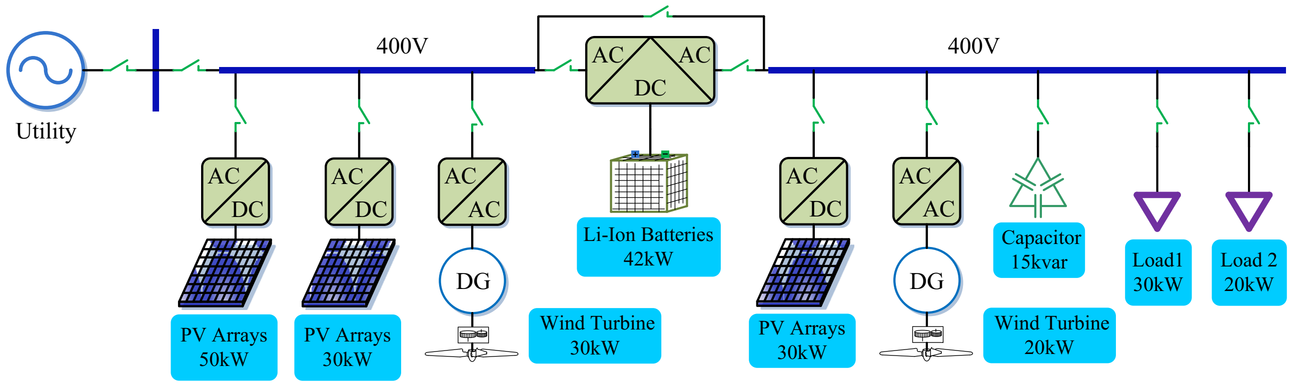

Fig. 19. Configuration of the micro-grid in Hunlunber.

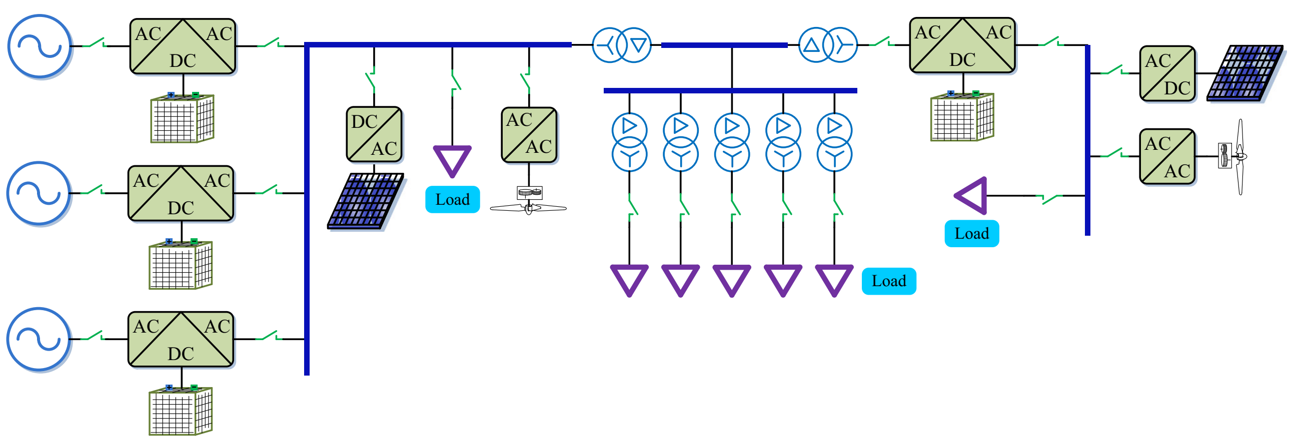

Fig. 20. Configuration of the micro-grid in Dongao Island.

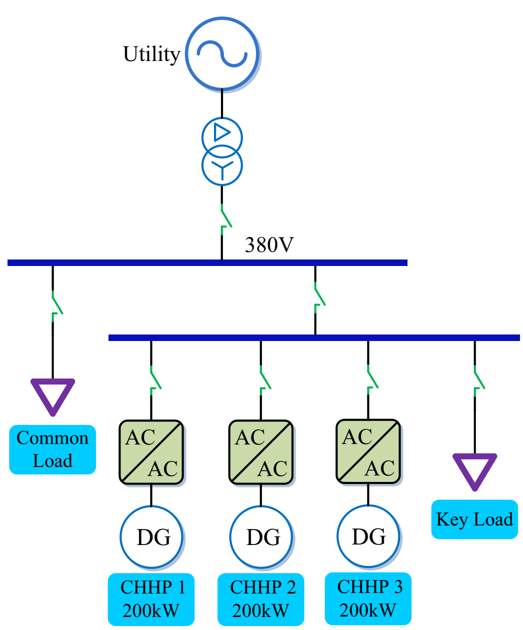

Fig. 21. Structure of the micro-grid by Southern China Power Grid.

ELDC are hugely different; therefore, how to optimally choose the capacities of such devices in a micro-grid with hybrid energy storage devices is also important.

- Comprehensive evaluation on the economic and environment benefits of micro-grids should be carried out to quantify the contribution of micro-grids on the low emission and green power supply. Especially, the economic model and bidding mechanism of the micro-grid under a power market condition need much more focuses.
- Information communication technology (ICT) of the micro-grid. Micro-grid will be a coordination of power flow and information flow in the near future. Therefore, the information flow of the micro-grid associated with EMS, protection units, supervisor units, and some other advanced controllers is of significance in a micro-grid R&D and demonstration project. To realize the information flow, some proper communication technologies and standards, such as IEC 61850 may pay much deeper role in such field.
- Coordination control of the micro-sources in a micro-grid. How to dispatch and schedule the multiple micro-sources in a micro-grid in an optimal and peer-to-peer way is an urgent issue of the micro-grid. Many possible strategies are carried out, such as centralized control, hierarchical control, droop control, and multi-agent control. However, the coordination control strategies are endless, and they are needed to be enhanced; on the other hand, some novel control strategies to avoid the drawbacks of these available ones are demanded. To organize and control the distributed, randomness, and uncontrollable renewable energy resources, some useful concepts, such as virtual synchronous generator or synchronverter [43], virtual power plant, may be good choices for the interfacing of RES and micro-grids. It cannot only make the grid-tied inverter work automatically and independently, but also can enhance the damping and inertia of the inverter to support the stability of the micro-grid.
- Coordination control of micro-grids, as well as micro-grid and distribution network. With the rapid implementations of micro-grid and distributed generation systems, the distribution network must be active. That is to say, the distribution network

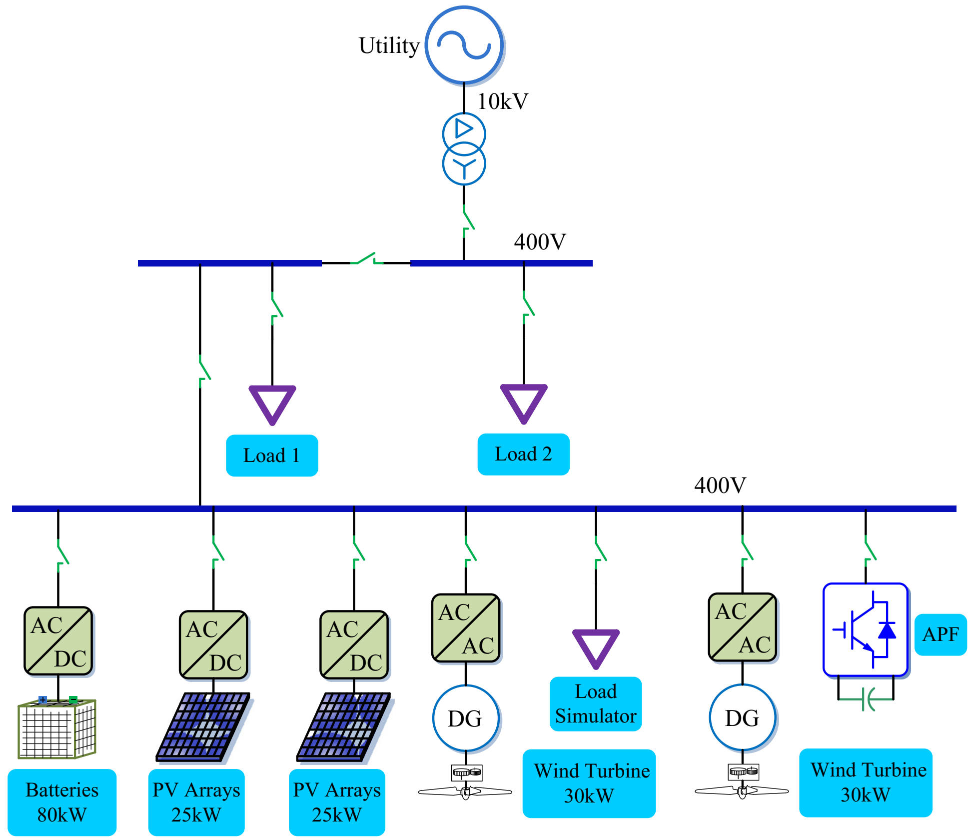

Fig. 22. Configuration of the micro-grid in Chengde.

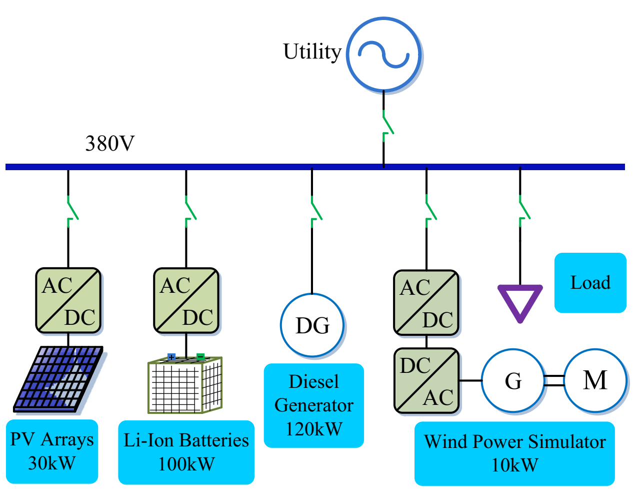

Fig. 23. Configuration of the micro-grid built in JEPRI.

will integrate many power sources in the terms of micro-grids or independent inverter-dominated sources. In such conditions, how to properly schedule and coordinate the micro-grids, as well as the micro-grid and active distribution network, will be a very important part of the secure, reliable, economic operation of micro-grids and distribution network.

- Seamless transform between different operation modes of a micro-grid. There is power interrupt (at least one to two periods) in many available micro-grids of China when the operation mode of the micro-grid is transferred. This kind of power interrupt mainly occurred at the transform from islanded mode to grid-tied mode due to the unavoidable response time for synchronization. Such power interrupt may be serious problem for the sensitive loads in the micro-grid. Therefore, some advanced control strategies and/or devices are emergently necessary.
- EMS of the micro-grid. To aim the reliable, optimal, and economic operation of the micro-grid, EMS is inescapable. An advanced EMS for micro-grid application should integrate the functionalities, such as state estimation, power generation forecast, supervisor, protection, control, and so on. Some multi-layer, multi-dimensional, and multi-perspective EMS for the micro-grid implementation should be paid much more attention.
- Hybrid energy storage. A micro-grid generally need much more than just one kind of energy storage device, due to the cost, power density and energy density, time response, and bulk of different energy storage devices are totally different. A hybrid energy storage system in the micro-grid should be a good choice for the power quality and cost-effective enhancement of the micro-grid. Therefore, despite the optimal selection of capacities mentioned before, the control strategies to optimally coordinate the different kind of energy storage devices are also very important and necessary.
- Protection technology of the micro-grid. Due to the bi-directional power flow in a micro-grid and the exchange flow between micro-grid and distribution network, it is hard to design and handle the protection units of micro-grids and distribution network. However, the toleration of grid-tied inverters on over-current and over-voltage is greatly lower than the ones of conventional generators. Thus, it is important to properly design and equip protection devices on an inverter-oriented distributed generation unit. Some related knowledge and technologies are urgently demanded.
- Power quality of the micro-grids. It is well-known that the micro-grid must meet some requirements on power quality

due to the standards of utility. However, from the viewpoint of micro-grid, the power quality has also greatly influence on its security, reliability, and economic operation. It has been well documented that the harmonic resonance in series and/or parallel will result in undesired trips of grid-tied inverters and challenges the stability of micro-grid [44,45]. Besides, the harmonic, unbalanced, and reactive current in the micro-grid will take up the capacities of grid-tied inverters, lines, and loads, even cause the noises and vibrations of electric machines. Additionally, the on-grid price of the micro-grid will affected by its power quality at PCC in the power quality market in the near future. Therefore, power quality enhancement approaches with cost-effective performance are greatly pleasure. To decrease the bulk, investment cost, maintenance and operation cost, and man-hour of a micro-grid, some devices can be embedded in multiple functionalities of many other independent devices, such as APF, dynamic voltage restorer (DVR), unified power quality conditioner (UPQC), and so on. For instance, a grid-tied inverter can be equipped with the functionality to enhance the power quality of micro-grid, which is named as multi-functional grid-tied inverter, as previously mentioned in Section 3.3.2 [46].

- Micro-grid is a mini power system in some sense. Therefore, some technology, like black-start, load shedding, load curtailment, etc., of a micro-grid should be investigated and confirmed in advance.
- Buildings are the mainly fields of the power consumption [47]. Smart buildings or intelligent buildings integrated with micro-grids are typical forms of the future micro-grids. The micro-grid-based home energy management system (HEMS) will be important part of the micro-grid R&D. It can also be looked forward that the vehicle-to-grid will be realized in the home-oriented micro-grids with the help of the HEMS.
- It can be expected that dc micro-grid will be an important part of the micro-grid in the near future. Because the dc micro-grid have a series of advantages, such as the reactive power issue in a dc micro-grid can be cancelled and the investment on lines will be decreased compared with a micro-grid in three-phase ac form. Besides, dc local loads can be directly fed by the dc micro-grid, which can greatly improve the efficiency of the micro-grid.

5. Conclusions

In this paper, the scenarios on the policies and demonstrations of micro-grids in China have been comprehensively reviewed. Some features, necessaries, and the trends of the micro-grid R&D and demonstration in China are conducted. It can be of significance for the world to know the great efforts and ongoing progresses on the micro-grids in China.

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